

# ELECTROMYOGRAPHIC ANALYSIS OF GLUTEAL RECRUITMENT: AN EXPLORATION OF ACTIVATION DURING JUMPING TASKS

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## ABSTRACT

**Background:** Inability to maintain proper alignment of the pelvis and femur due to gluteal muscle weakness has been associated with numerous lower extremity pathologies. Therefore, many lower extremity rehabilitation and injury prevention programs employ exercises that target gluteal muscle strength and activation. While information regarding muscle activation during exercises that are typically done in the beginning stages of rehabilitation is available, evidence regarding the gluteal muscle activity during more functional and advanced exercises used during later stages of rehabilitation is sparse.

**Purpose:** To explore the recruitment of the gluteal muscles during jumping tasks in healthy participants to determine which jumping exercise best elicits gluteal muscle activation.

**Study Design:** Prospective cohort design

**Methods:** Eighteen healthy recreational athletes ( $23.5 \pm 3.8$  years, 8M/10F,  $67.56 \pm 3.2$  inches,  $66.73 \pm 9.5$  kg) completed three trials of four jumping tasks: hurdle jump, split jump, V2 lateral jump, and cross-over jump in random order. Surface EMG electrodes were placed on each participant's bilateral gluteus medius (GMed) and maximus (GMax) to measure muscle activity during the jumping tasks. Maximal voluntary isometric muscle contraction (MVIC) was established for each muscle group in order to express each jumping task as a percentage of MVIC and allow standardized comparison across participants. EMG data were analyzed for all jumps using a root-mean-square algorithm and smoothed with a 62.5 millisecond time reference. Rank ordering of muscle activation during jumping tasks was performed utilizing the peak percent MVIC recorded during each jumping task.

**Results:** Three of the jumping tasks produced greater than 70% MVIC of the GMed muscle. In rank order from highest EMG value to lowest, these jumping tasks were: crossover jump (103% MVIC), hurdle jump (93.2% MVIC), and V2 lateral jump (84.7% MVIC). Two of the exercises recruited GMax with values greater than 70% MVIC. In rank order from highest EMG value to lowest, these jumping tasks were: hurdle jump (76.8% MVIC) and split jump (73.1% MVIC). Only the hurdle jump produced greater than 70% MVIC for both GMed and GMax muscles.

**Conclusions:** The jumping task that resulted in greatest activation of the GMed was the crossover jump, while hurdle jump led to the greatest activation of the GMax. The high %MVIC for the GMed during the crossover jump may be attributed to lack of maximal effort or lack of motivation during performance of maximal contractions during the manual muscle testing. Alternatively, substantial co-contraction of core muscles during the crossover jumping task may have led to higher values.

**Level of Evidence:** 2b Individual Cohort Study

**Keywords:** Electromyography, gluteus maximus, gluteus medius, jumping

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## INTRODUCTION

There is little evidence that a particular type of exercise for the gluteal muscles is any better than another.<sup>1</sup> Gluteal muscle weakness is associated with several common orthopedic injuries including patellofemoral pain syndrome, anterior cruciate ligament (ACL) sprains, and chronic ankle instability.<sup>2-7</sup> Weakness of both the gluteus medius (GMed) and maximus (GMax) may influence joint-loading patterns and lower extremity muscular control. Lower extremity injury prevention programs commonly use exercises that target the gluteal muscles but a wide range of exercises are used in the clinic and the implementation of these exercises varies by clinician. Electromyography (EMG) is often used to evaluate the muscle activity occurring during movements or exercises in order to determine the potential for muscle strengthening effects.

Ekstrom et al. investigated EMG activation during nine rehabilitation exercises that target the core, trunk, hip and thigh muscles in thirty healthy adults.<sup>1</sup> The exercises chosen included exercises commonly used in the clinic: side bridge, unilateral-bridge, lateral step-up, quadruped arm/lower extremity lift, active hip abduction, using the Dynamic Edge device for lateral motion that mimics slalom skiing, forward lunge, bridge, and prone-bridge. In healthy subjects, the vastus medialis was best recruited by the lateral step-up (85%  $\pm$  17) and lunge exercise (76%  $\pm$  19); the side-bridge was effective for activation of the GMed (74%  $\pm$  30) and external oblique muscles (69%  $\pm$  26), and the quadruped arm/lower extremity lift exercise may provide a strengthening stimulus for the GMax muscle (56%  $\pm$  22). Active hip abduction, bridge, prone-bridge, and using the Dynamic Edge device each produced less than 45% MVIC in the GMax and GMed indicating less benefit in terms of activation levels for strengthening and more for endurance activities.<sup>1</sup>

Authors have suggested that returning an athlete to sport (RTS) is one of the most challenging, complex, and difficult decisions that are made by a sports medicine team.<sup>8</sup> Authors suggest that the majority of the literature indicates that a battery of tests are necessary to assess various outcome parameters and establish criterion-based clinical reasoning for RTS. Three of the items that are included by researchers

specifically related to ACL injury/surgery and RTS are jump tests, hop tests, and sport-specific testing.<sup>8</sup> The differences noted by the researchers were that jump tests should be done first before hop tests as jump tests involve using both legs to jump and a concentration should be on controlling propulsive forces for the eccentric deceleration landing. This is commonly stated in the clinic as trying to land softly. In contrast, hop tests use only one leg. Recently, Buckthorpe suggested that factors in need of more exploration in RTS decision-making include: 1. Explosive neuromuscular performance; 2. Movement quality deficits associated with re-injury risk, particularly the need to re-train optimal sport-specific movement patterns; 3. The influence of fatigue; and 4. Sport-specific re-training prior to RTS, with particular attention to an insufficient development of chronic training load.<sup>9</sup> Buckthorpe suggests that it is likely that most rehabilitation approaches are not comprehensive enough, do not provide sufficient intensity or are not specific enough to fully prepare an athlete for the demands of their sport.<sup>9</sup>

As gluteal muscle weakness is associated with several common orthopedic injuries and many lower extremity rehabilitation and injury prevention programs employ exercises that target gluteal muscle strength and activation, the purpose of the current study was to explore the recruitment of the gluteal muscles during jumping tasks in healthy participants to determine which jumping exercise best elicits gluteal muscle activation. It was hypothesized that the crossover jump would generate greater gluteal activation due to the eccentric aspects associated with this jump.

## METHODS

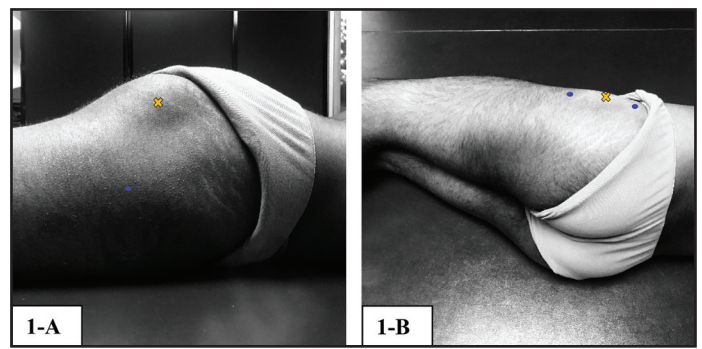
### Participants

This study used a prospective design to explore the gluteal recruitment in 18 healthy recreational athletes. The participants were recruited from the Northern Arizona University community and volunteered to participate. Participants were required to be: between 18 to 45 years old, recreationally active, participate in physical activity at least 60 minutes, three days per week, and be proficient in English in order to complete the Kinesiophobia outcome questionnaire. Exclusion criteria were currently pregnant, current

bout of lower extremity or back pain in the prior six months, recent history of lower extremity surgery (within the prior two years), or current symptoms of injury or pain when performing exercises over the prior three months. Participants meeting study criteria were provided information about the purpose of the research and the potential risks. Participants provided written informed consent prior to participation and the protocol for this study was approved by the Northern Arizona University Institutional Review Board. The Kinesiophobia outcome questionnaire was used to ensure there was no reluctance by the participant to perform plyometric exercises due to the fear of movement from a previous musculoskeletal injury. The privacy of the participants was maintained when applying and removing the electrodes.

### Testing Procedures

The participants were first prepared for EMG electrode placement by abrading the skin and cleaning the skin with 70% isopropyl alcohol wipes in order to maximize the electrode adherence to the skin and minimize skin impedance.<sup>10</sup> The EMG electrodes (DelSys, Inc., Boston, MA, USA: interelectrode distance 10 mm; amplification factor 1000 (20–450 Hz); CMMR @ 60 Hz N 80 dB; input impedance  $> 10^{15}/0.2 \Omega//pF$ ) were placed bilaterally over the GMed and GMax muscles, approximately parallel to the muscle fiber orientation in accordance with SENIAM (surface EMG for a non-invasive assessment of muscles) guidelines (Figure 1).<sup>11,12</sup> Electrodes were secured using a double-sided adhesive skin interface to minimize motion artifact and ensure consistent electrode placement throughout testing. Placement was confirmed by viewing EMG signals while separately activating each muscle.<sup>13,14</sup> Participants then completed a five minute warm-up on a stationary cycle ergometer at a self-selected pace. Following a practice session, a five-second MVIC was performed three times in the standard manual muscle testing protocol positions for each gluteal muscle with one minute of rest between each contraction.<sup>13</sup> A strap was secured around the distal femur during muscle testing for both muscles to ensure standardization of resistance.<sup>15</sup> Verbal encouragement to concentrate on the muscle contraction was given with each MVIC trial.<sup>16</sup> Order of MVICs was counterbalanced to avoid any potential neuromuscular fatigue.



**Figure 1.** *Electrode positioning on the left gluteus maximus (1-A) and gluteus medius (1-B) muscles.*

The researcher then demonstrated and explained the jumping tasks (hurdle jump, split jump, V2 lateral jump, and cross-over jump) as described in Appendix A. The jumping tasks were randomized using a random pattern generator in order to avoid any order bias due to fatigue. Participants performed six repetitions of each jumping task, one practice and five repetitions that were used for data collection. To ensure proper jumping technique, each participant was allowed one good practice task prior to data collection and any necessary verbal and tactile cues by the instructing researcher. Three sets of five repetitions were chosen to reduce the effects of fatigue while providing enough trials to ensure reliability of EMG data. Two minutes of rest was given between the performances of each jumping task. If the participants did not display proper performance during a plyometric exercise set, the trial was discarded and repeated.

### Data Analyses

Data were recorded bilaterally for each of the four muscles, rectified and smoothed individually using a root mean-square algorithm, and smoothed with a 62.5 millisecond (msec) time reference. Peak amplitudes were averaged over a 125 msec window of time, 62.5 msec prior to peak and 62.5 msec after the peak.

To determine MVIC, the middle 3/5<sup>th</sup> time for each manual muscle test trial was isolated and the peak value determined. The highest peak value out of the three sets of five repetitions was recorded and determined to be the MVIC.<sup>15</sup> In order to establish %MVIC for each exercise performed by an individual participant, data were collected for the last

three repetitions of each exercise. If it was difficult to determine a repetition starting and stopping point on visual analysis of EMG data, then the middle 3/5<sup>th</sup> of the total time to perform the three repetitions was analyzed. The highest peak out of the three repetitions was then divided by MVIC to yield %MVIC for that participant.

### Statistical Analyses

To determine %MVIC values for rank ordering of jumping tasks, the %MVIC for each muscle was averaged between all participants for each exercise. Normalized mean EMG signal amplitudes were compared among jumping tasks using a repeated-measures 1-way analysis of variance (ANOVA), with an a priori level of significance of 0.05 for both muscles. In addition, a reliability analysis was conducted using intraclass correlation coefficients (ICCs) across the three repetitions of each jumping task to confirm that the EMG measures were stable within participants. An ICC less than 0.40 indicated poor reliability, 0.40 to 0.74 indicated moderate-to-good reliability, and greater than 0.75 indicated excellent reliability. SPSS, Version 25.0 (SPSS Inc, Chicago, IL) was used for all statistical analysis.<sup>17</sup> A sample of 18 participants allowed us to detect a power of .794 with an  $\alpha$  of 0.05.

### RESULTS

Eighteen healthy recreational athletes ( $23.5 \pm 3.8$  years, 8M/10F,  $67.56 \pm 3.2$  inches,  $66.73 \pm 9.5$  kg) participated in the study. All participants successfully completed the jumping tasks. The reliability analysis across the three repetitions for each jumping task resulted in ICC values ranging from .894 to .969, with standard error of measurement (SEM) values between 5% and 12% MVIC for the GMed. The GMax data resulted in ICC values ranging from .620 to .954, with SEM values between 6% and 28% MVIC (Table 1). These data suggest moderate to high reliability across trials for both muscles during each jumping task.

There was a significant difference observed among the four jumping tasks for the GMed mean muscle activity ( $F_{5,102} = 11.4$ ,  $p < .0001$ ). Three of the jumping tasks produced greater than 70% MVIC of the GMed muscle. In rank order from highest EMG value to lowest, these jumping tasks were: crossover jump (103% MVIC), hurdle jump (93.2% MVIC), and V2 jump (84.7% MVIC) (Table 2). Normalized mean amplitudes for the GMax muscle activity during the four jumping tasks are shown in Table 3. A significant difference was observed for GMax mean amplitudes among the four jumping tasks ( $F_{5,102} = 11.2$ ,

**Table 1.** Results for gluteus maximus and medius reliability analysis for each jumping task (n = 18).

Table 1	Within-Subject Reliability (n=18)			
	Gluteus Maximus		Gluteus Medius	
	ICC <sub>3,1</sub>	SEM (%MVIC)	ICC <sub>3,1</sub>	SEM (%MVIC)
Hurdle Jump	0.933	5	0.962	6
Split Jump	0.946	6	0.969	6
V2 Jump	0.954	6	0.955	6
Crossover Jump	0.499	28	0.894	12
Abbreviations: ICC, intraclass correlation coefficient; MVIC, maximal voluntary isometric contraction; SEM, standard error of measurement				

**Table 2.** Results for gluteus medius recruitment, %MVIC and rank for all jumping tasks (n = 18).

Table 2	Normalized Gluteus Medius Mean Signal Amplitude (n=18), %MVIC and Rank			
Jumping Task	%MVIC Gluteus Medius (Rt)	Rank Gluteus Medius (Rt)	%MVIC Gluteus Medius (Lt)	Rank Gluteus Medius (Lt)
Crossover Jump (Lt)	103.66%	1	81.75%	4
Hurdle Jump (Lt)	93.23%	2	82.68%	3
Hurdle Jump (Rt)	84.68%	3	88.82%	2
Crossover Jump (Rt)	84.47%	4	97.89%	1
V2 Jump	84.34%	5	71.19%	5
Split Jump	52.75%	6	57.25%	6



**Table 3.** Results for gluteus maximus recruitment, %MVIC and rank for all jumping tasks (n = 18).

Table 3	Normalized Gluteus Maximus Mean Signal Amplitude (n=18), %MVIC and Rank			
Jumping Task	%MVIC Gluteus Maximus (Rt)	Rank Gluteus Maximus (Rt)	%MVIC Gluteus Maximus (Lt)	Rank Gluteus Maximus (Lt)
Hurdle Jump (Rt)	76.86%	1	18.96%	6
Split Jump	73.08%	2	70.45%	1
Crossover Jump (Rt)	63.04%	3	41.00%	4
V2 Jump	54.52%	4	25.24%	5
Crossover Jump (Lt)	37.68%	5	51.20%	3
Hurdle Jump (Lt)	27.97%	6	61.90%	2

$p < .0001$ ) Two of the exercises recruited GMax with values greater than 70% MVIC. In rank order from highest EMG value to lowest, these jumping tasks were: hurdle jump (76.8% MVIC) and split jump (73.1% MVIC) (Table 3). Only hurdle jump produced greater than 70% MVIC for both GMed and GMax muscles.

## DISCUSSION

The objective of this study was to explore the recruitment of the gluteal muscles during jumping tasks in healthy participants to determine which jumping exercise best elicits gluteal muscle activation. In the current study, the greatest activation of both the GMed and GMax muscles during jumping in healthy participants occurred during the hurdle jump. Moderate to high reliability occurred for all jumping activities suggesting the gluteal recruitment was repeatable across all participants and therefore can be used in the clinic. When considering specific gluteal muscle recruitment, the GMed demonstrated the greatest activation with the crossover jump and the GMax demonstrated the greatest activation with the hurdle jump. These recruitment levels may be explained by the relative differences in the external moments developed during the lower extremity movement against gravitational force in different planes. The high MVIC for the GMed muscle during the crossover jump may be attributed to lack of maximal effort or lack of motivation during performance of maximal contractions while doing the manual muscle testing. This may also be true for other jumping tasks used in the study. Alternatively, substantial co-contraction of core muscles during the crossover jumping task may have led to higher values. Co-contraction of core muscles may substitute

for inadequate GMax and GMed recruitment during jumping tasks.

Several researchers have reported gluteal muscle weakness associations with several common orthopedic injuries to include ACL prevention programs,<sup>18</sup> patellar femoral pain syndrome,<sup>19,20</sup> overuse injuries at the knee,<sup>21</sup> patellofemoral osteoarthritis,<sup>22,23</sup> ilio-tibial band syndrome,<sup>24</sup> meniscal injury,<sup>25</sup> and low back pain.<sup>26</sup> When considering the association of gluteal muscle weakness with these conditions, it is not known when a patient presents to the clinic if the patient had the gluteal muscle weakness prior to injury which may need to be a focus to prevent injury, but it is known that the patient presents with gluteal weakness during the rehabilitation process. The results of the current study provide clinicians with exercises that specifically target the gluteal muscles that could be used to prevent injuries or in the later stages of rehab when the individual is prepared for progressive RTS exercises. When considering the different conditions associated with gluteal muscle weakness, inappropriate gluteal recruitment needs to be addressed by matching the appropriate exercise to the needs of an individual.

Throughout rehabilitation, emphasis is placed on improving gluteal activity as this reduces the knee valgus motion by controlling hip adduction and hip internal rotation.<sup>27-31</sup> Ground reaction forces during walking and running is thought to reach 1.5 and 2.5 times the individual's body weight<sup>32</sup> whereas in jumping, ground reaction forces can reach up to seven times the individual's body weight.<sup>33</sup> In patients that collapse into knee valgus with landing, the result may include body weight forces beyond what the medial knee can handle. Preventing knee valgus

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limits the forces directed to the medial knee.<sup>27-29,31</sup> The GMed specifically has been targeted in many studies as it plays a role in pelvic stability in weight-bearing activities<sup>27,34,35</sup> and combined with the GMax, comprises 33% of the hip musculature<sup>36</sup> in terms of cross sectional area and both muscles are essential for athletic, non-athletic, and post-surgical rehabilitation.<sup>37</sup> The progression of weight-bearing activities needs to be specific to the patient but should also be advanced from the early stages of rehabilitation to the latter stages in accordance to the SAID (Specific Adaptation to Imposed Demands) principle.<sup>38</sup>

Several authors have investigated common therapeutic exercises such as bridging that are typically performed in the clinic during the early stages of rehabilitation.<sup>1,15,39-41</sup> Jumping activities or plyometrics are considered important as patient's progress through rehabilitation and enter the return to sport phase of rehabilitation. Specifically jumping exercises are thought to improve landing and cutting by increasing muscle activation and improving neuromuscular effectiveness in terms of recruitment timing of the muscles that are specific to sport.<sup>42</sup> Stepping and cutting exercises that are performed in the frontal plane have been shown to recruit the gluteals better than similar exercises that are performed in the sagittal plane.<sup>43,44</sup> There are limited studies investigating plyometrics that are done in multiple planes.<sup>43-45</sup> Struminger et al found that single-leg sagittal plane plyometrics produced the greatest activation of the GMed and GMax compared to 180 degree jumps.<sup>18</sup> The researchers specifically looked at preparatory and loading phases of the plyometrics and found that the GMax was activated more during the landing phase of the jumps. The researchers suggested that more muscle fibers of the GMax are best recruited to perform hip extension during the sagittal plane exercises.<sup>18</sup> More research needs to be done to investigate specific plane plyometrics to assist in the latter stage of rehabilitation.

In the latter stage of rehabilitation, current approaches regarding exercise progression do not always facilitate the patient to RTS. Buckthorpe has suggested that most rehabilitation approaches do not provide a comprehensive approach and do not provide sufficient intensity or specificity to prepare an athlete for the demands of sport.<sup>9</sup> In a recent commentary,

Buckthorpe et al suggested that the GMax acts as a tri-planar stabilizer in movement and functions in conjunction with GMed and gluteus minimus to stabilize the hip. Collectively, the gluteal muscles produce large amounts of force and power to contribute to hip extension and therefore need to be recruited at high levels for athletic activities. Buckthorpe et al provide a holistic approach that the authors of the current study recommend to the reader.

### Limitations

This study has some limitations. The participants in the current study were recreationally active so specific application to athletes that routinely make these types of jumps may be limited. Future studies could investigate athletes that routinely jump within their sport. There is always a possibility of cross talk using surface electrodes, however the authors attempted to minimize the error by following the standardized methods of applying and securing the surface electrodes. The variability of the EMG signal found in the current study, while acceptable, may indicate the dynamic nature of these multiplanar jumping tasks. Additionally, it is difficult to determine if the participants generated a true maximal voluntary contraction for each muscle tested secondary to lack of effort. Efforts were made to encourage maximal effort for each participant verbally to improve participation. Lastly, even though EMG is useful to gain knowledge about muscle activation patterns and to observe differences in the muscle activity, caution should be used with interpretation of these results. Collection of more detailed kinematics and kinetics data would have strengthened the EMG interpretation of the difference in activity levels among jumping tasks.

### CONCLUSIONS

Multiple orthopedic conditions result in gluteal weakness or inhibition. In the early stages of rehabilitation, gluteal activation needs to be initiated and progressed. In the current study, the jumping task that showed the maximal GMed muscle activation was the crossover jump, while hurdle jump led to the greatest activation of the GMax. The rank ordered list provided in this study may help form exercise selections during the latter stages of the rehabilitation. Incorporating plyometric exercises

in the latter stages of rehabilitation and specifically those that activate the GMax and GMed are critical for clinicians to consider before return to sports that require jumping.

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## APPENDIX A

### Single leg sagittal plane hurdle hop

The subject is instructed to start standing on the dominant foot behind a line a distance 30% of his/her height from the end line. A 10.16 cm tall hurdle is placed halfway between the subject's feet and the (end line). The subject jumped forward over the hurdle in the sagittal plane. The subject lands with the dominant foot on the end line and is not allowed to touch down with the non-dominant leg. On the next beat of the metronome, the subject jumps backward over the hurdle and returns to the initial starting position.

### Split Squat Jump

The subject is instructed to begin in a lunge position with the non-dominant leg immediately lateral to the landing area and the dominant limb behind the non-dominate leg. The subject jumps in the air while

moving the non-dominant limb backward and immediately the dominant limb forward onto the landing area, landing in a lunge position. On the next beat of the metronome, the subject jumps as high as possible and switched the legs back to the starting position.

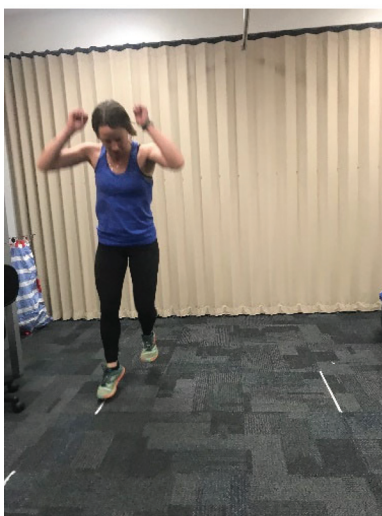
### V2 Jumps

V2 skate jumps consists of three different phases. Starting position is standing on one leg with the other leg slightly abducted. The participant then jumps horizontally and aims to land on the white mark which is 131 cm from the starting position for females and 165 cm from the starting position for males. The participant should land on the opposite mark on the opposite leg and upon landing conducts a small hop vertically into the air. On landing of the small hop, the participant will jump horizontally to land on the opposite leg on the starting marker and resume the start position.

Starting position:



Middle position:



Ending Position:



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### Crossover Skate Jumps

Starting position is established by crossing the jumping leg over the other leg with the hip externally rotated so that the heel is abducted farther than the

toes. The participant then jumps horizontally off of the jumping leg as far as possible. The participant lands on the opposite leg with the knee flexed about 20 degrees in an athletic position.

Starting Position:



Middle Position:



Ending Position:

